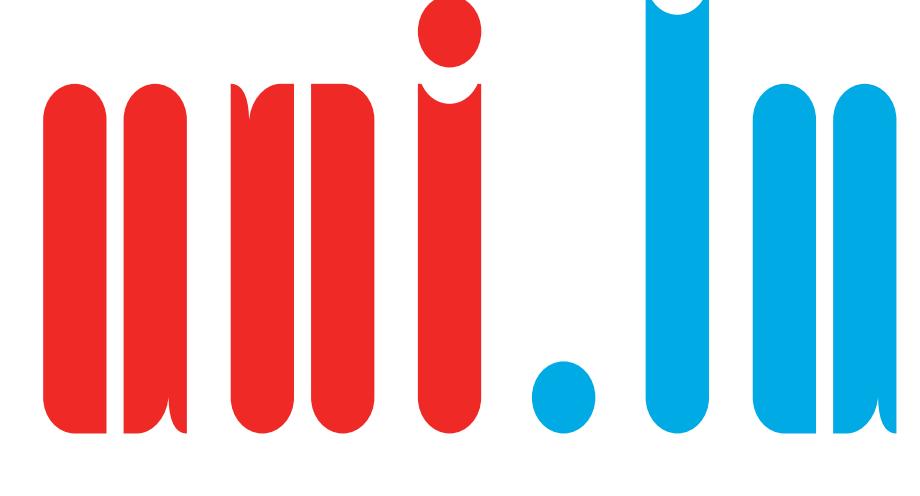# Evaluating the Performance of Numerical Weather Prediction Models for Precipitation and Temperature in Luxembourg & the Greater Region: Insights from WRF and WRFDA 3D-Var

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Abstract

This study evaluates the Weather Research and Forecasting (WRF) model, with and without WRFDA 3D-VAR data assimilation, for precipitation and temperature forecasts in Luxembourg and the Greater Region during June–July 2021, a period marked by severe flooding. Conventional meteorological observations and Global Navigation Satellite System(GNSS) Zenith Total Delay (ZTD) data were assimilated into WRF, using Global Forecast System (GFS) data for initial conditions. Precipitation forecasts were validated against NASA's GPM IMERG, RADAR data and against regional station measurements. Results demonstrate that data assimilation enhances the WRF model's ability to replicate the spatial distribution and intensity of precipitation, with visual comparisons (e.g., July 14, 2021) showing improved alignment with satellite and RADARobservations post-assimilation. Quantitatively, data assimilation reduces bias in precipitation and temperature forecasts at most stations, with mean absolute error (MAE) and symmetric mean absolute percentage error (SMAPE) often improving, though root mean square error (RMSE) exhibits mixed outcomes.

Keywords: NWP, WRF, Flash flood, Weather forecast, High-Resolution, GNSS, ZTD

Introduction

Flash floods differ from alluvial floods in terms of their rapid onset and little warning, making them challenging to predict [1]. Predicting flash floods requires accurate forecasts of extreme precipitation events and a precise understanding of local hydrological conditions [2]. Improvements in short-term weather forecasting and knowledge of hydrological conditions are crucial for better prediction and management of flash flood risks [3].
Flood events with major damage, in Luxembourg, are known from January 1993, December 1993, January 1995, January 2003, January 2011, June 2018 and July 2021 [4].
We will be developing an NWP model for nowcasting, integrating ZTD data, static information, and meteorological data. As a part of our research, we conducted a case study for the July 2021 event.The WRF model was deployed on an HPC environment through containerization, though this specific instance was evaluated on a local machine.

Study Area and Methodology

The study investigates Luxembourg's diverse landscapes and oceanic climate, with 700–1,200 mm annual rainfall and 8–12°C temperatures[5], using a 12 km WRF model initialized with GFS, GNSS ZTD, SYNOP, radiosonde, and Tropospheric Airborne Meteorological Data Reporting (TAMDAR) data.
Figure 1 illustrates the NWP model domain, while Figure 2 shows WRF flow chart and Table 1 outlines its key configurations.
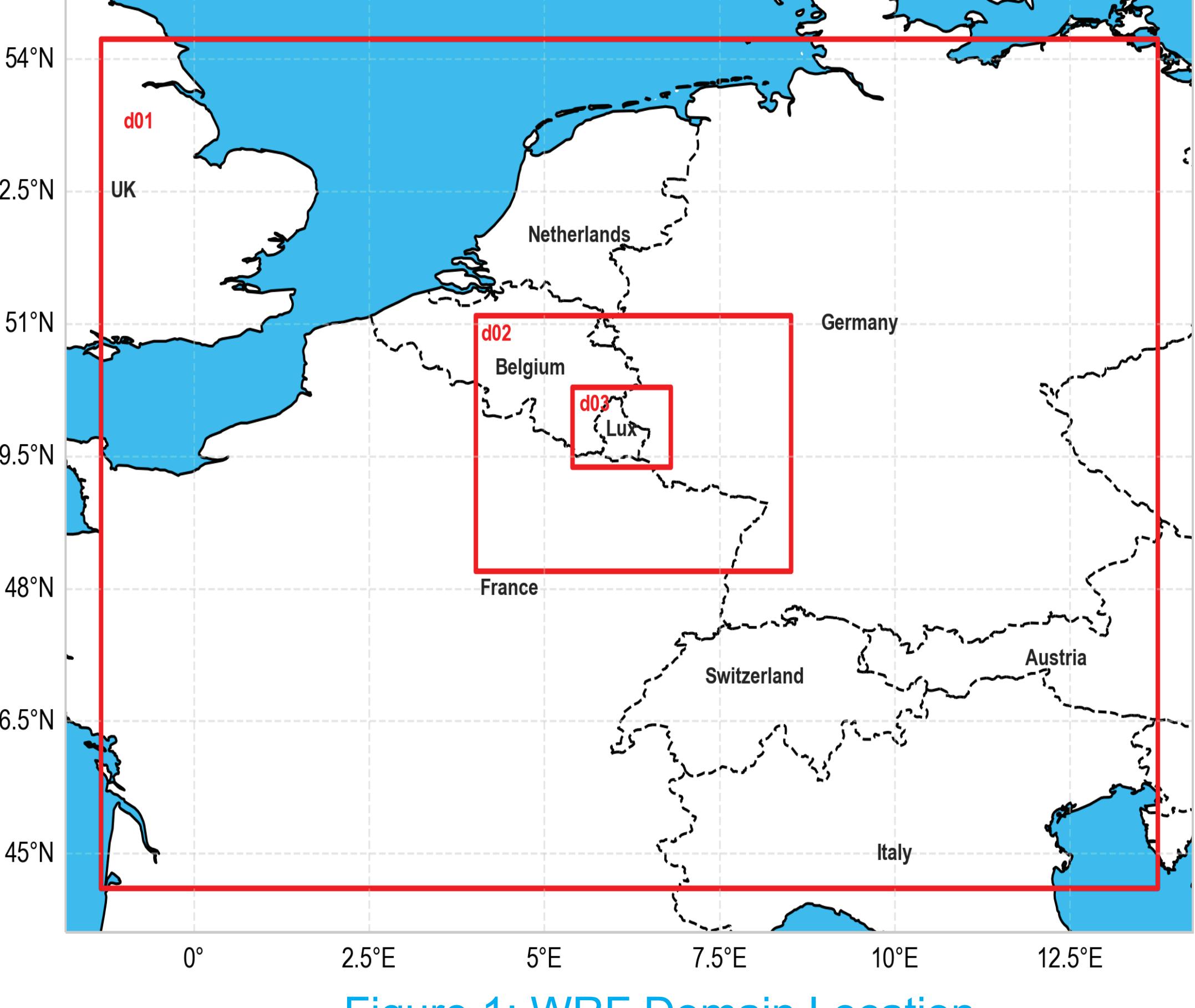

Figure 1: WRF Domain Location

Figure 2: WRF Flow Chart

Table 1: WRF Salient Features

Parameter	Description
Domain Location	Greater Region
Domain Size / Horizontal Grid Spacing	120 × 120 grid points, 12 km resolution
Vertical Levels	33
Static Data	MODIS Land Use (30") Soil Temperature (1") Orography (1" - 30m) Green Fraction (MODIS)
Meteorological Data	GFS
Output Interval	6 hr

The study employs the WRF model with WRFDA 3D-VAR to assimilate GNSS ZTD, SYNOP, radiosonde (TEMP), and TAMDAR data, using GFS for initial and boundary conditions, over the Greater Region. It extracts meteorological variables using Python, interpolating data to match station locations. Precipitation forecasts are compared with NASA GPM IMERG (0.1 deg), RADAR and regional station data, while temperature forecasts are validated against station observations, using metrics like MAE, RMSE, SMAPE, and bias. Regional data in Luxembourg were collected from Administration des Services Techniques de l'Agriculture (ASTA) and outside luxembourg this data was collected from National Oceanic and Atmospheric Administration (NOAA).
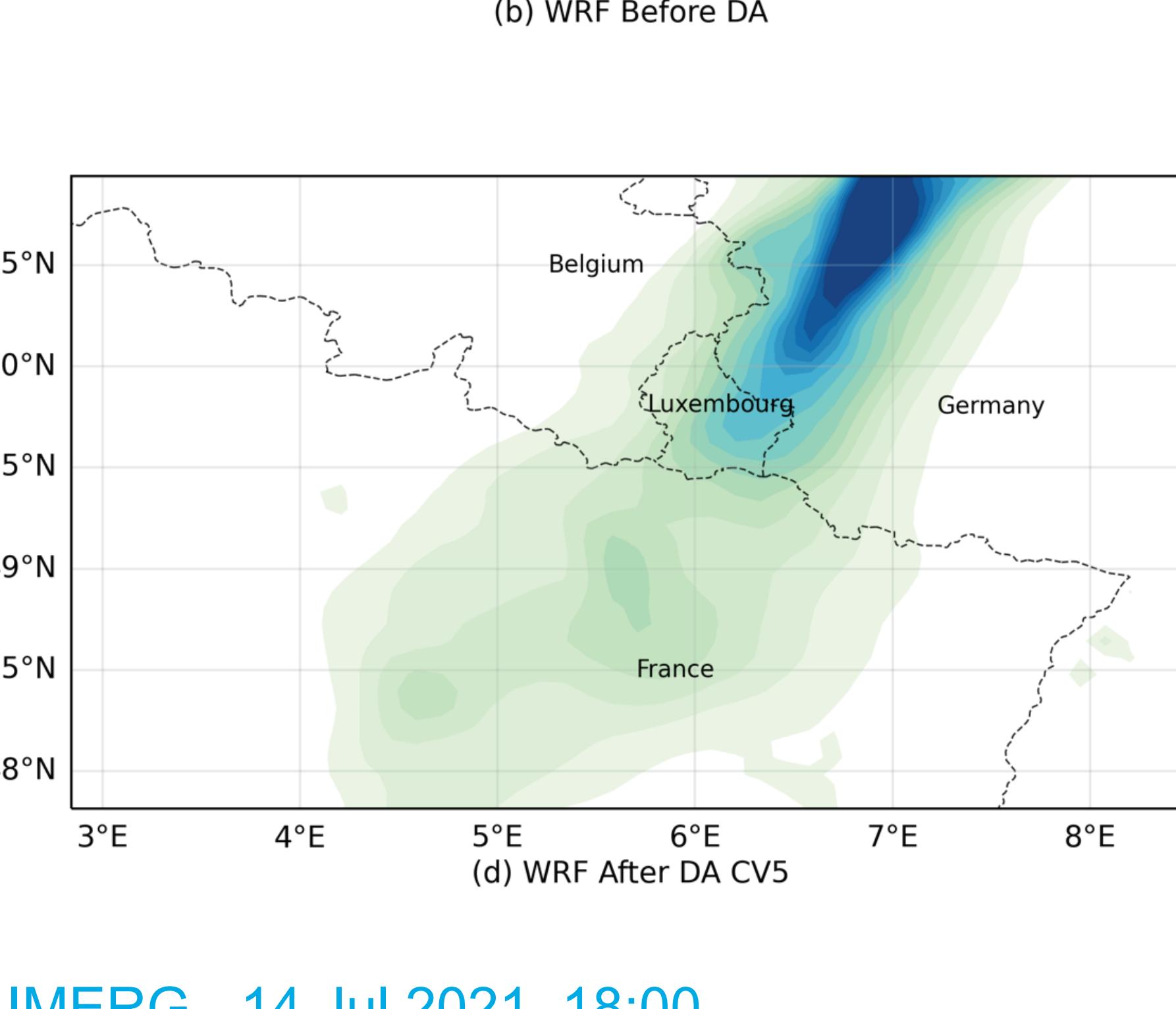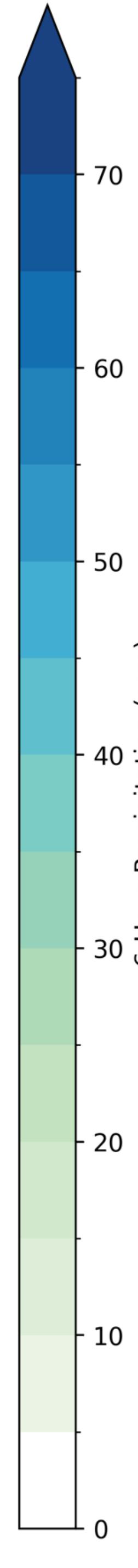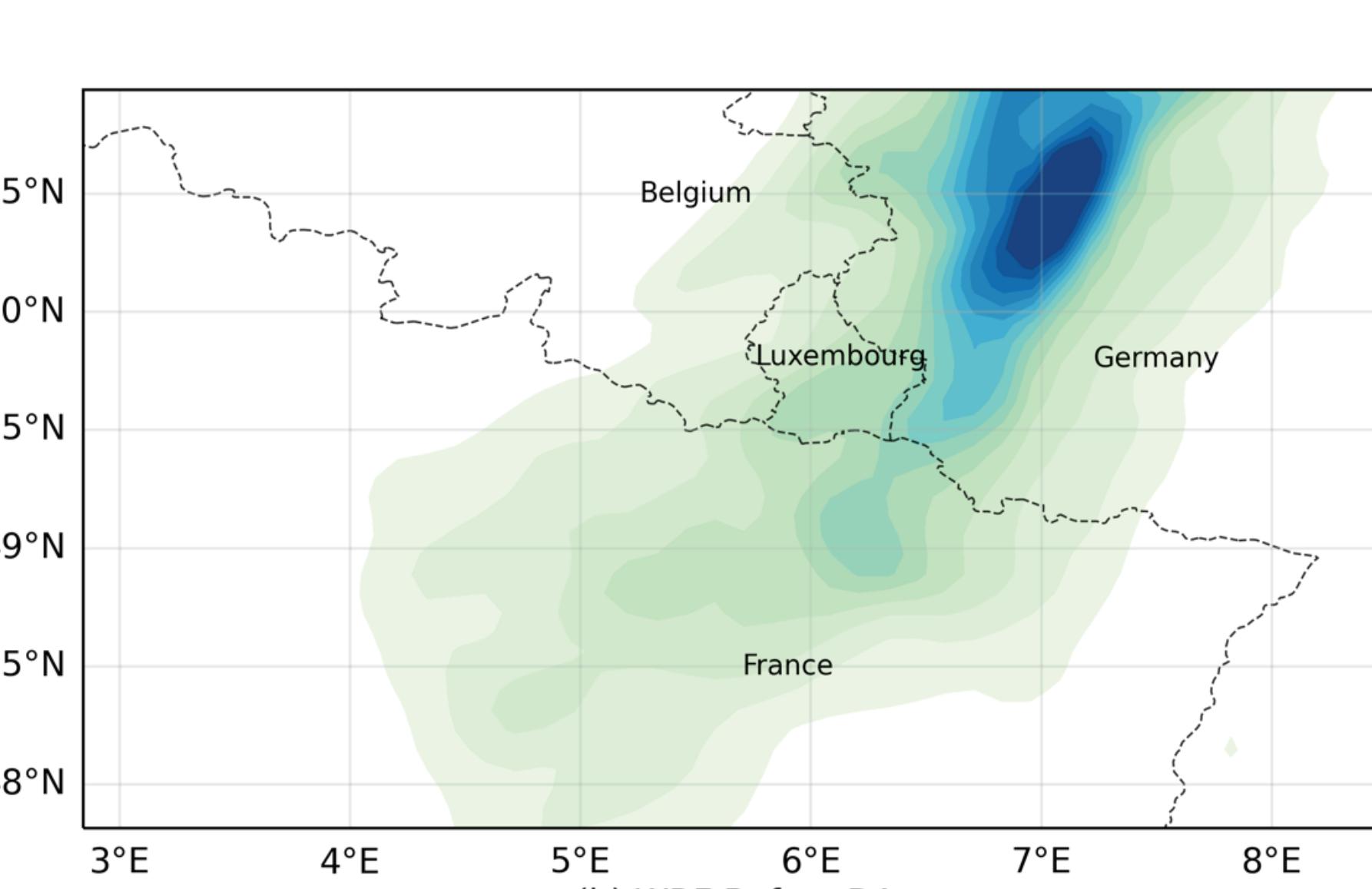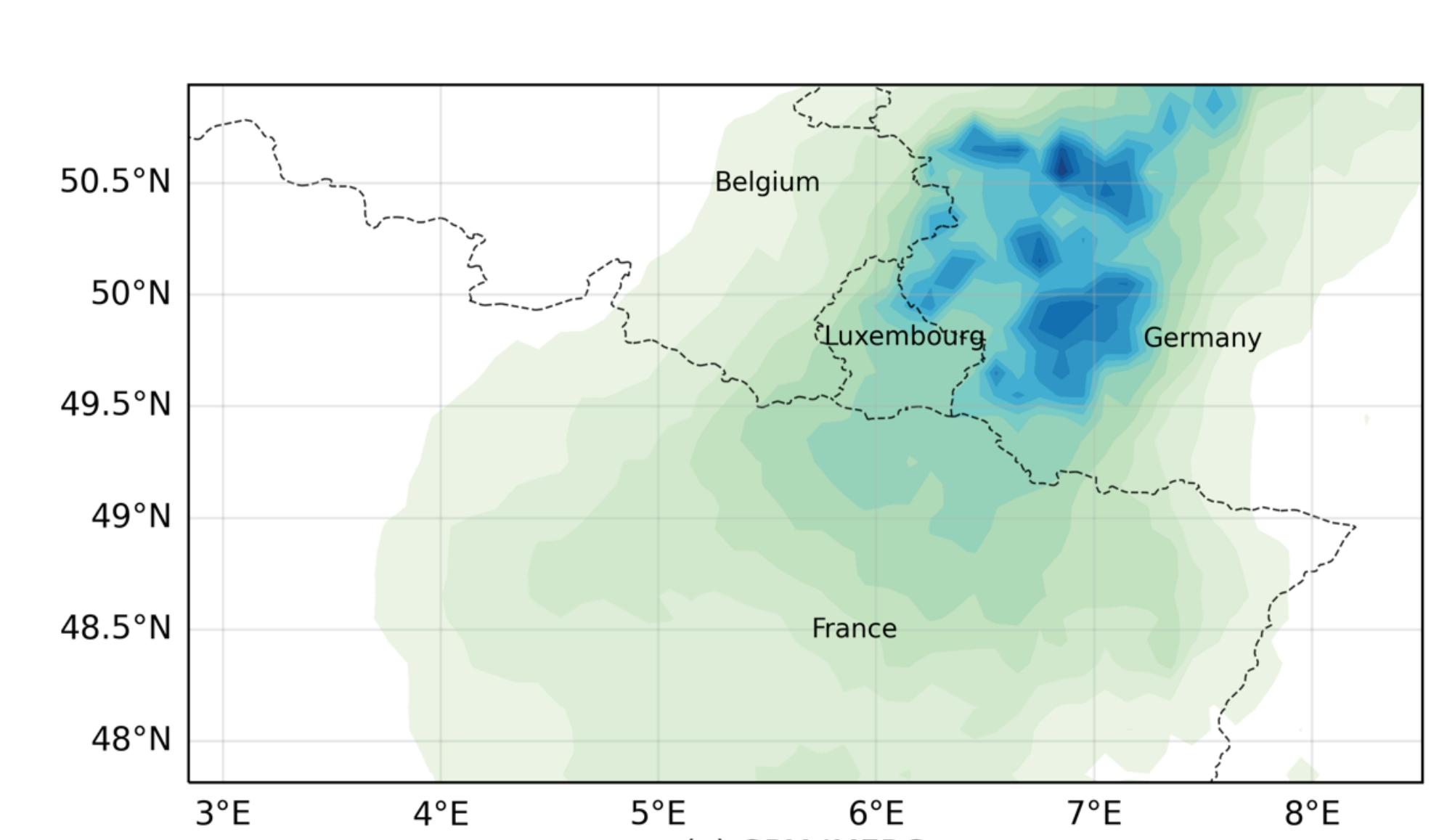

Figure 3: Stations locations used for validtion

Figure 4: Stations locations for assimilation
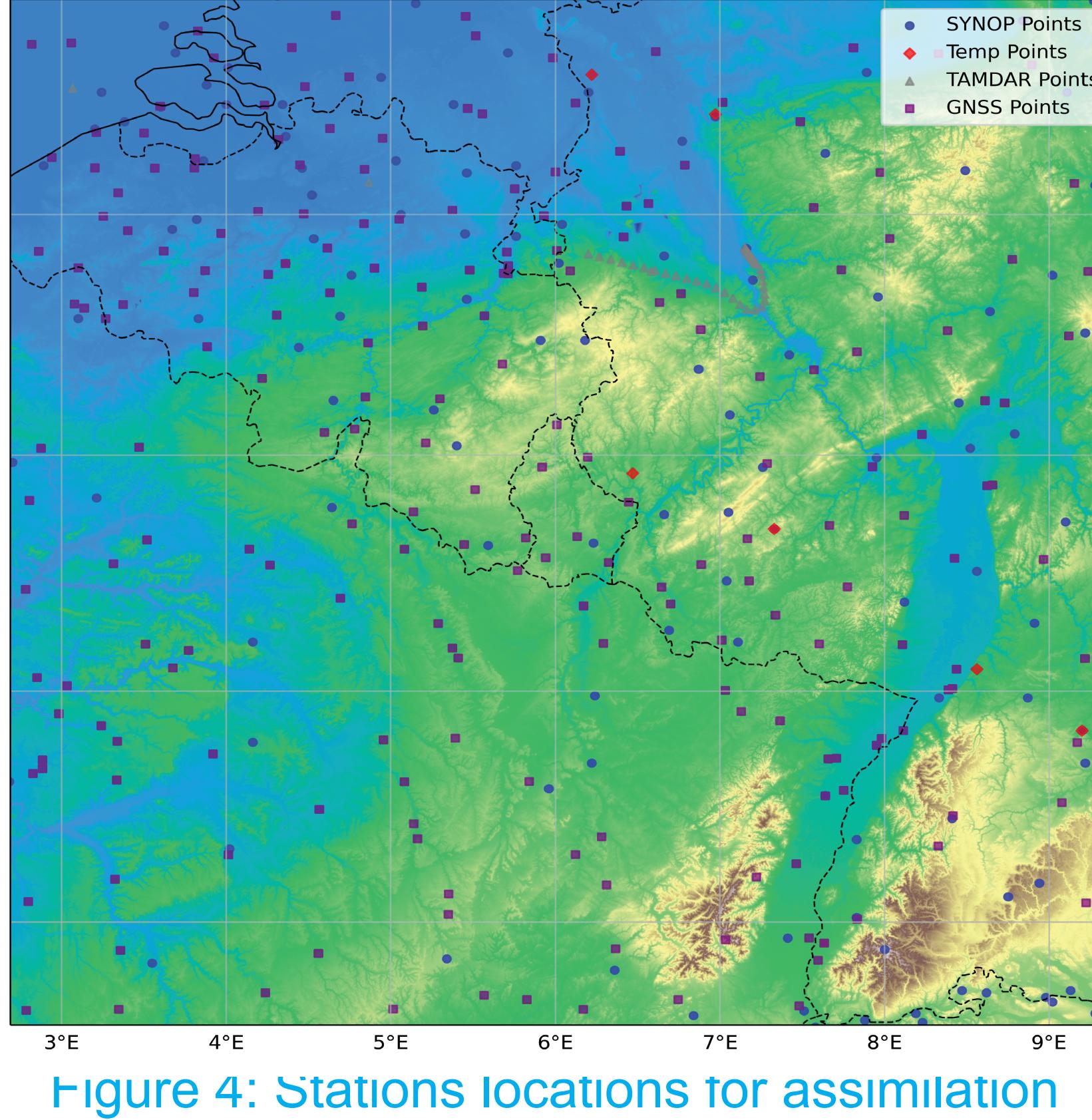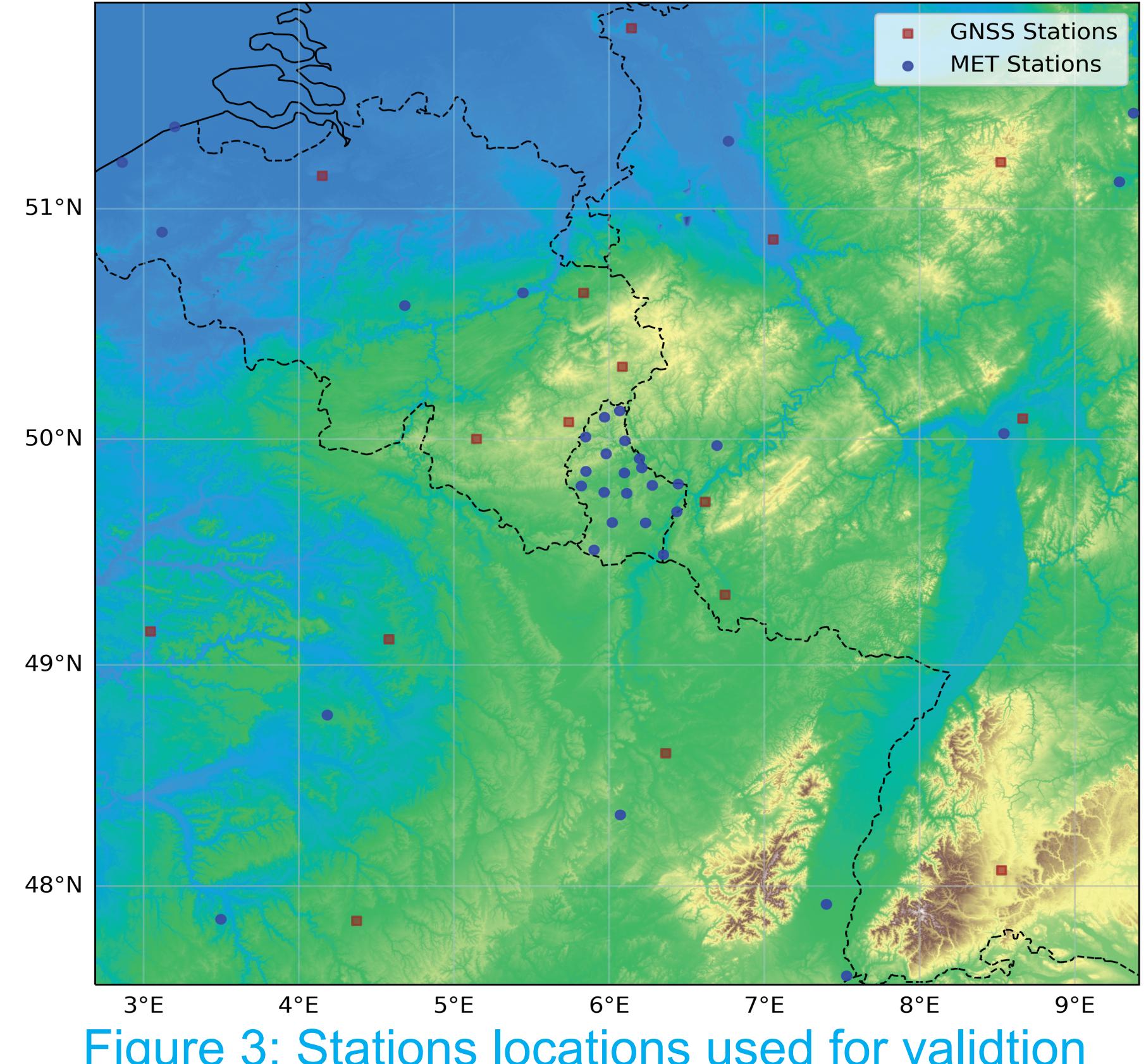
Results

Figure 5: WRF Forecast vs. GPM_IMERG - 14 Jul 2021, 18:00

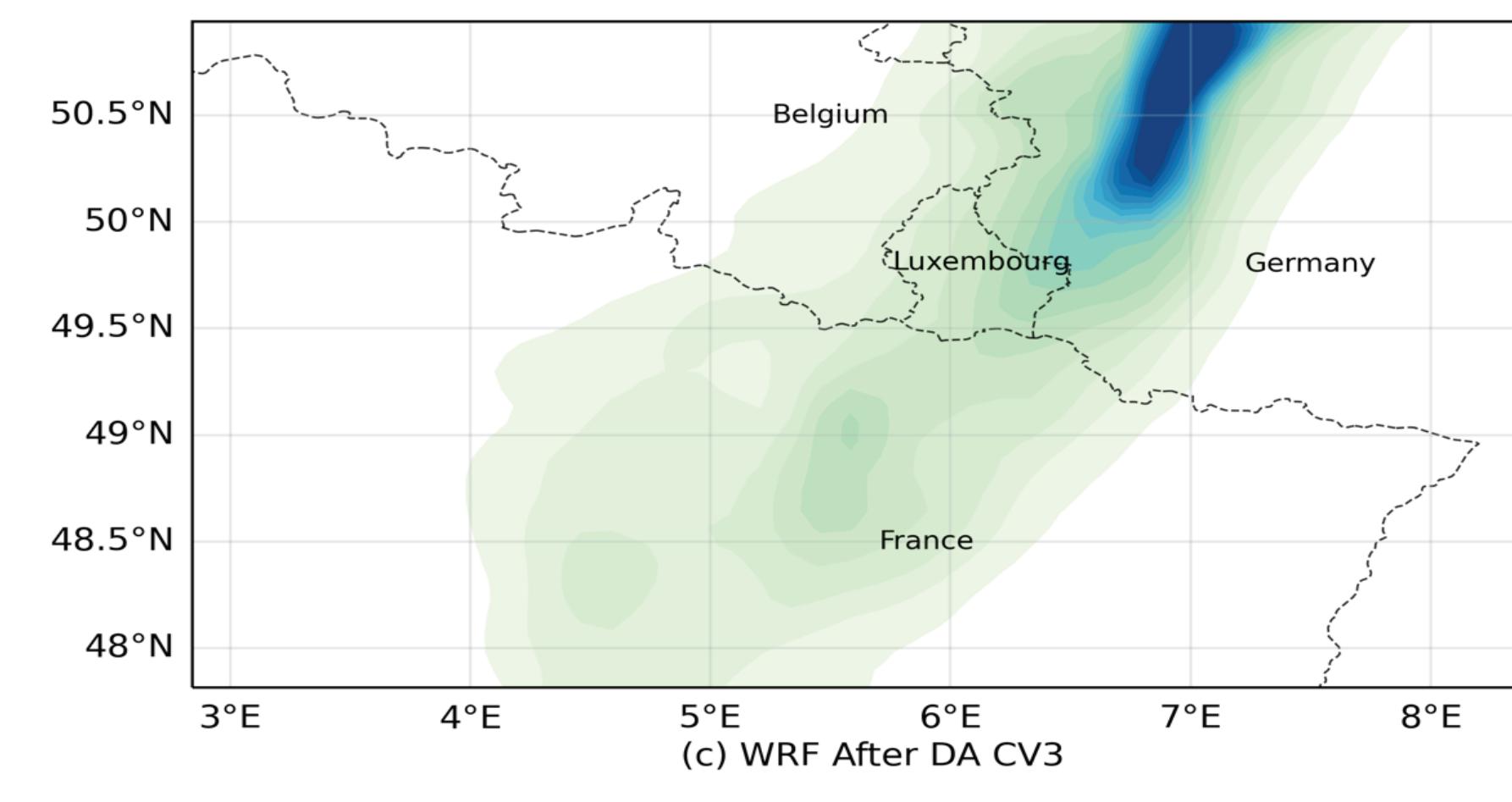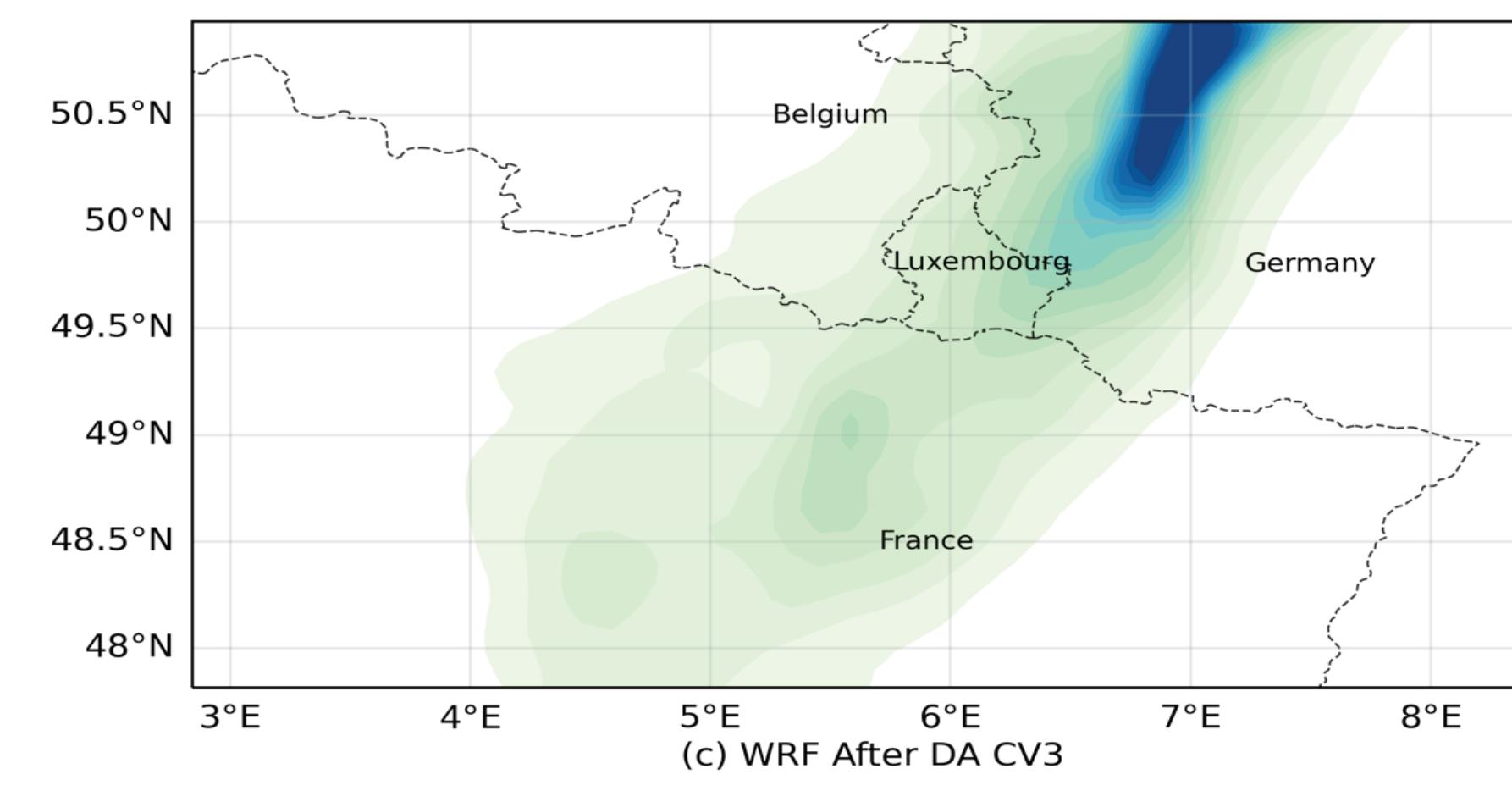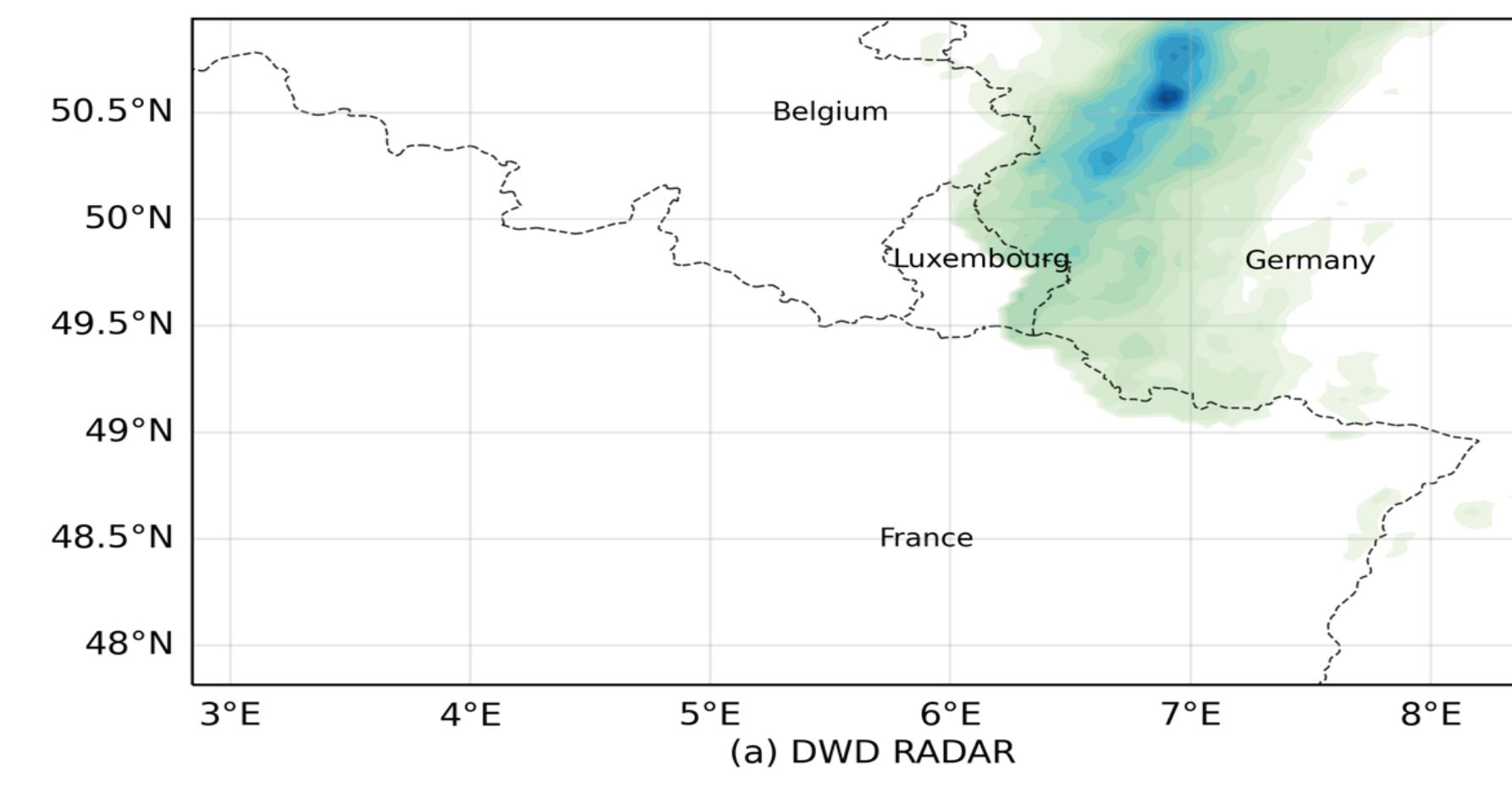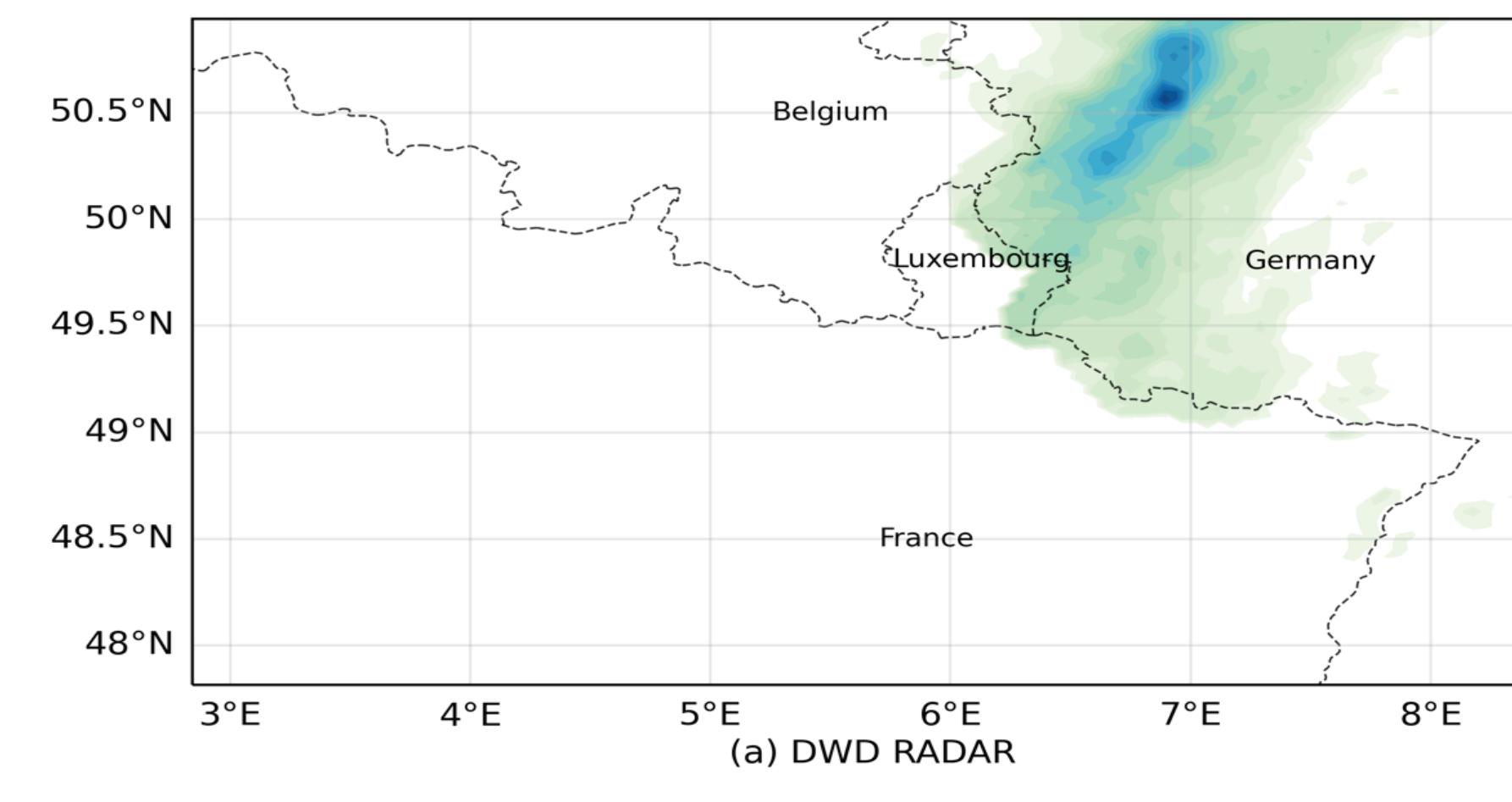
Figure 7: WRF Forecast vs. DWD RADAR- 14 Jul 2021, 18:00

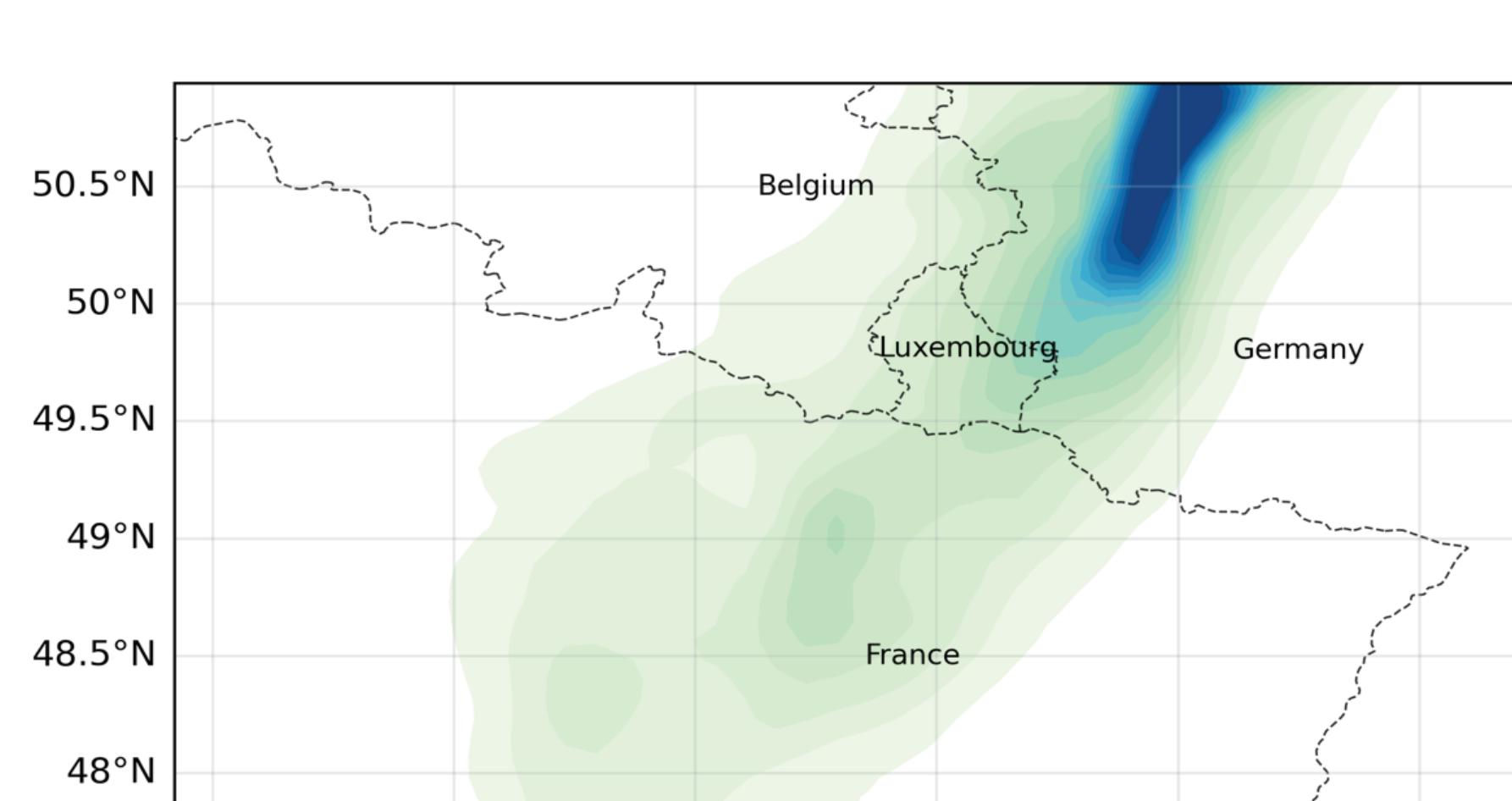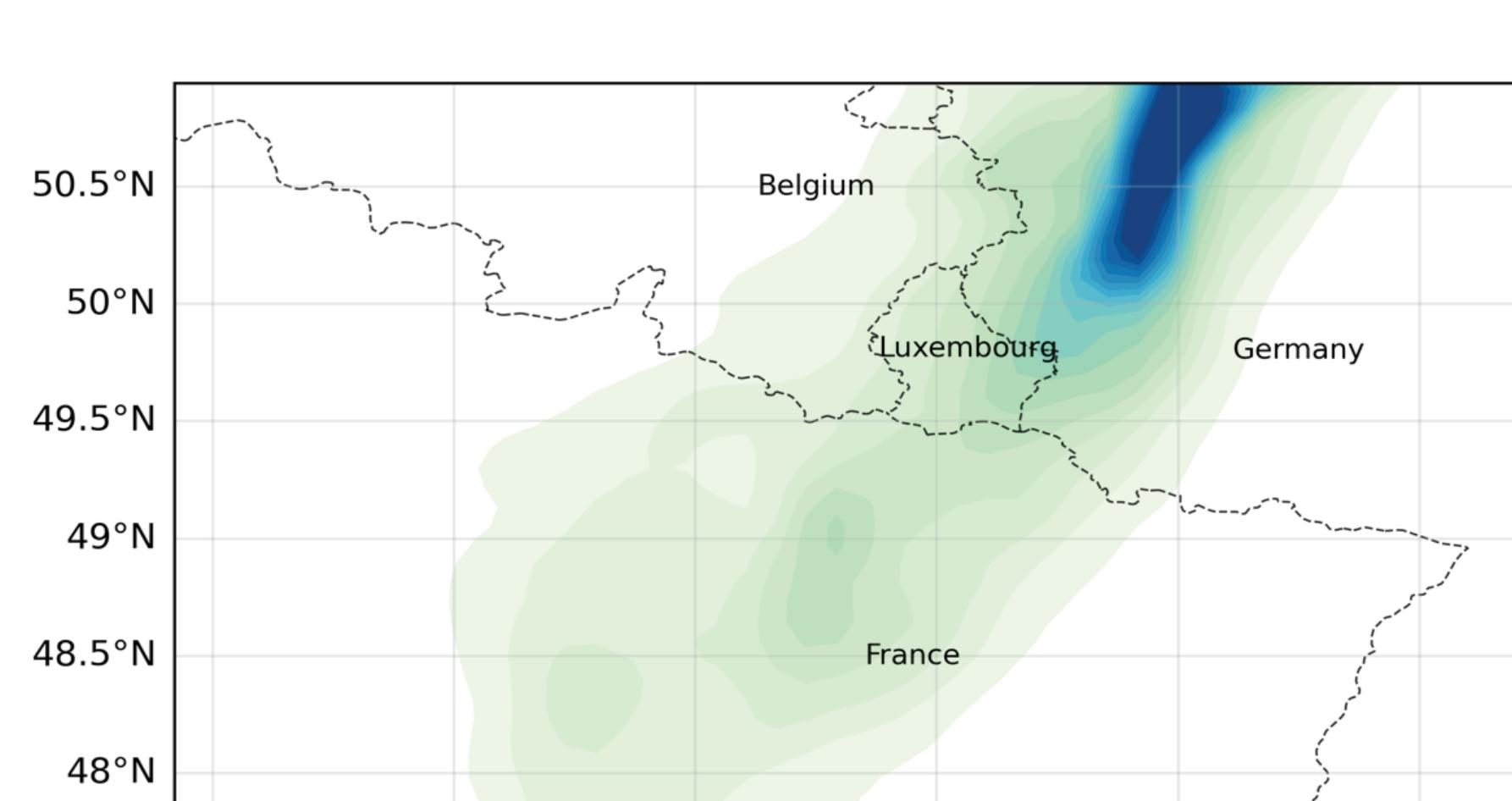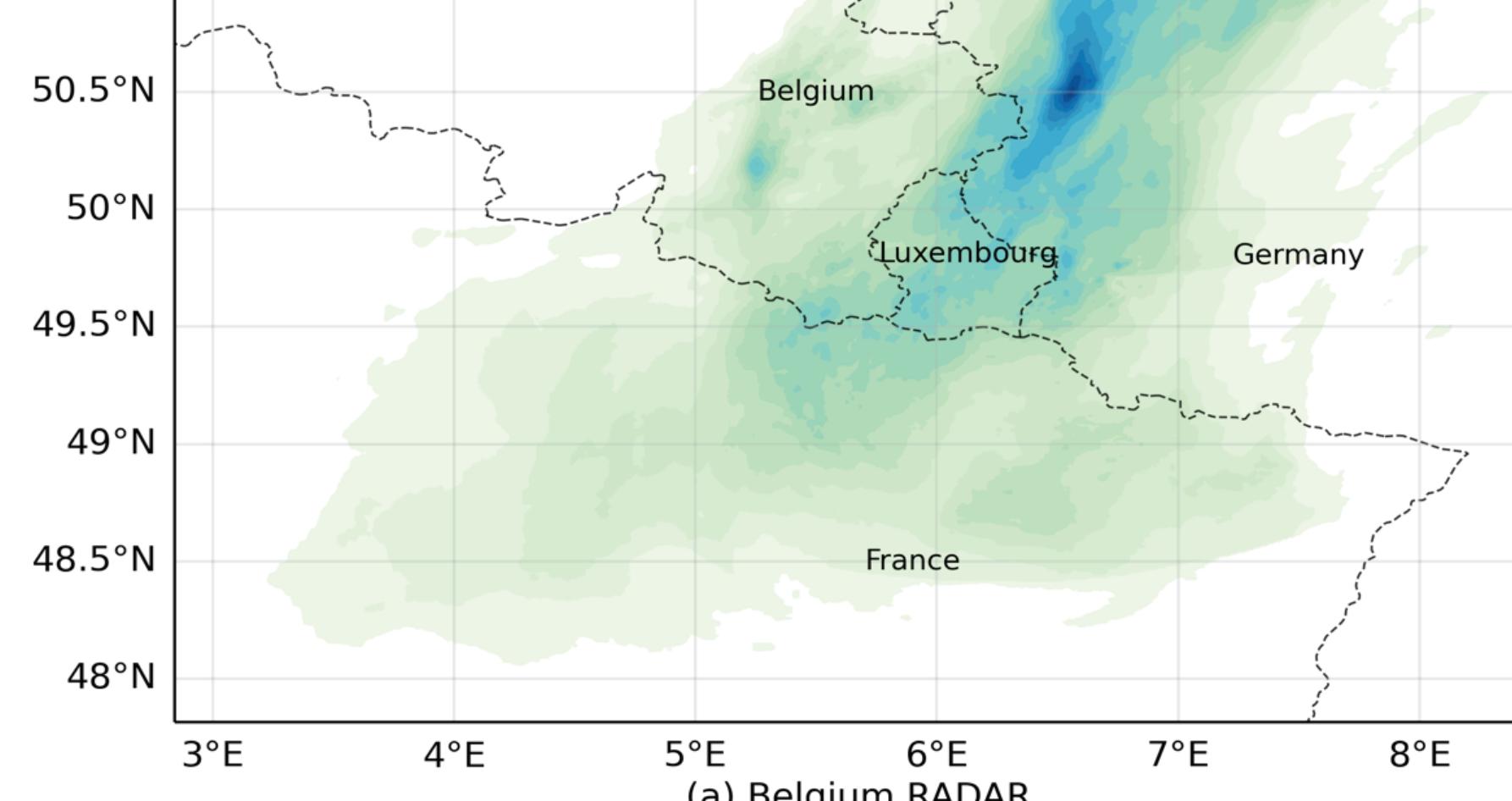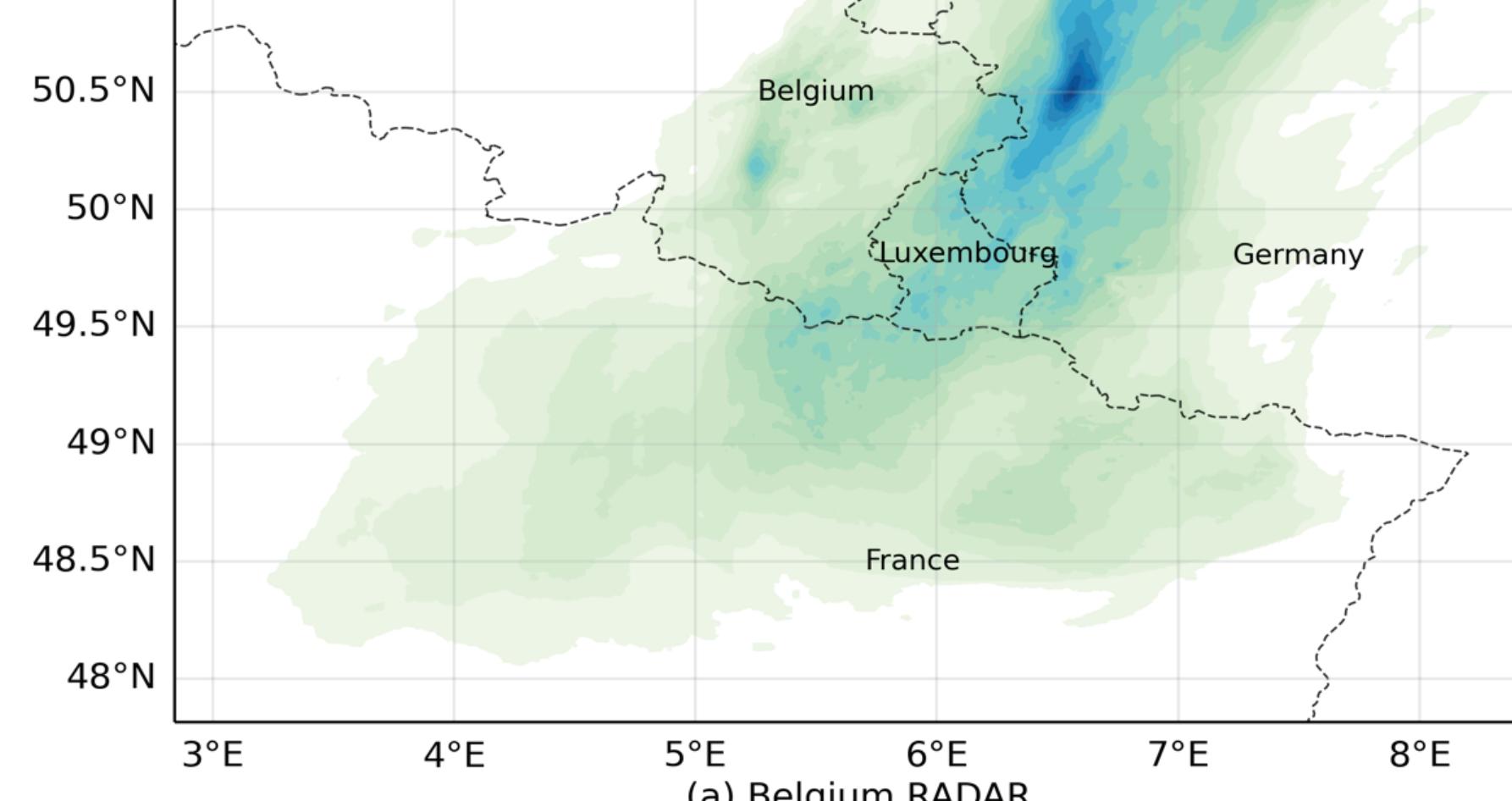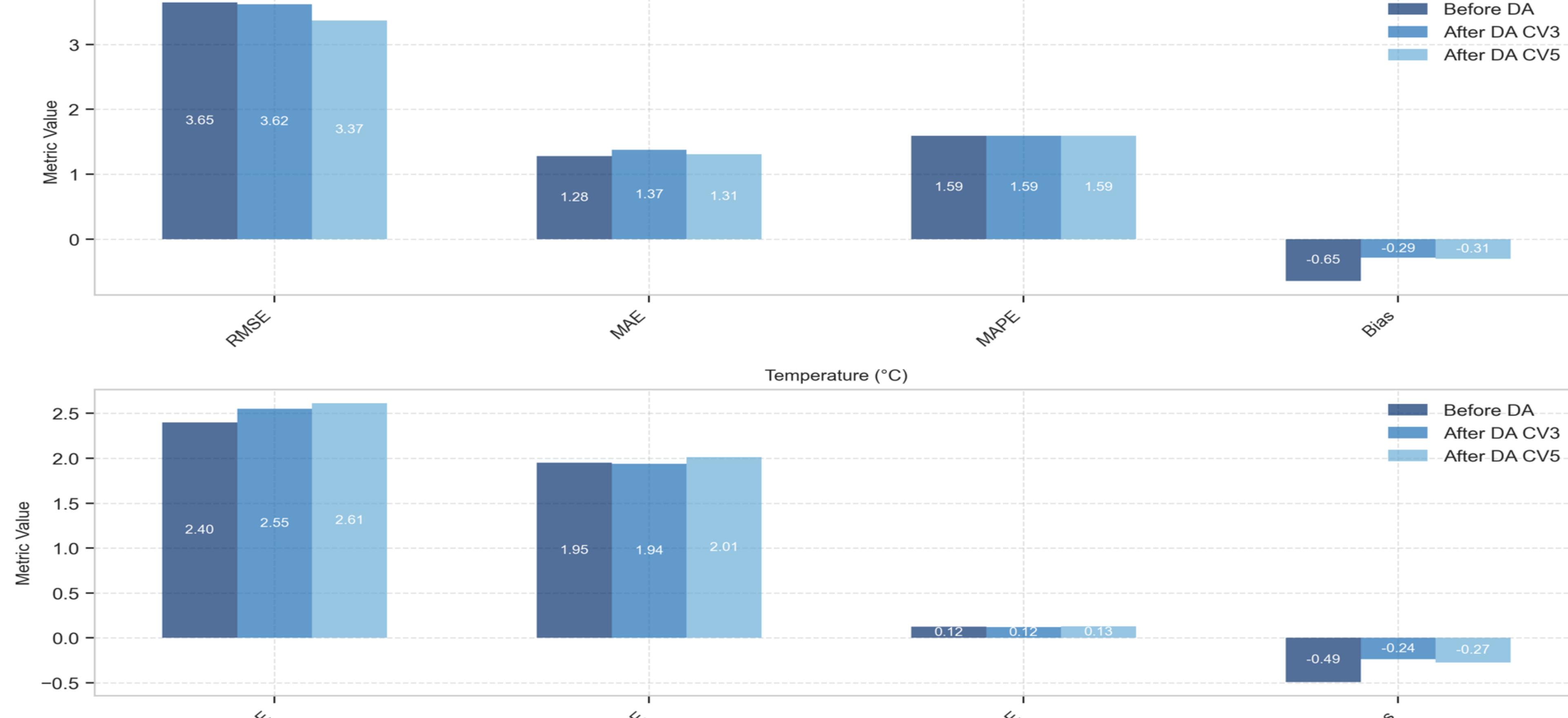Figure 8: WRF Forecast vs. Belgium RADAR- 14 Jul 2021, 18:00

Figure 9: WRF Simulation vs Observed Data Luxembourg
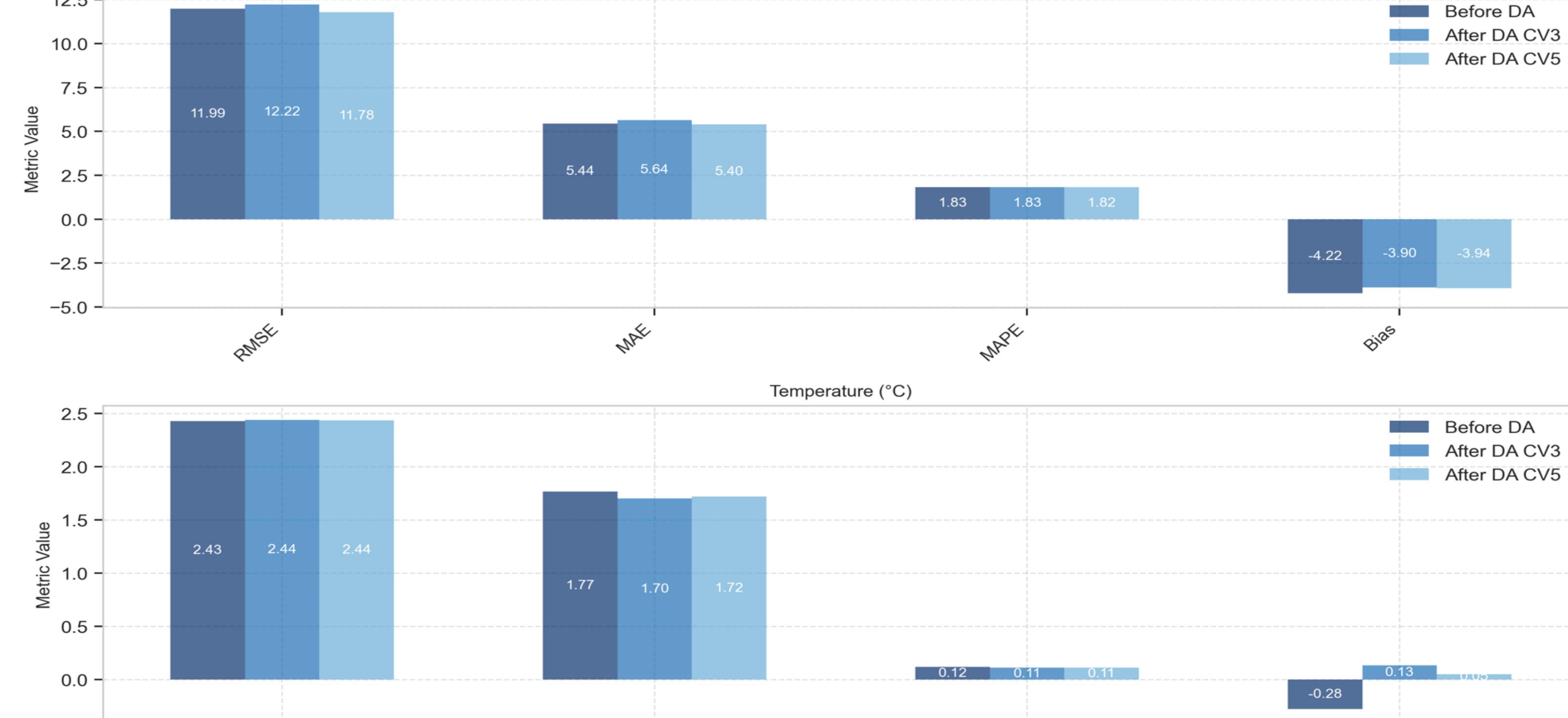

Figure 10: WRF Simulation vs Observed Data outside Luxembourg

Conclusion

• From visual comparison, data assimilation with CV5 most effectively improves WRF precipitation forecasts, aligning them closely with GPM IMERG, Belgium Radar, and DWD Radar.
• From comparing observed and WRF simulation results, data assimilation with CV5 reduces bias and enhances precipitation and temperature forecast accuracy in the Greater Region, though improvements across stations and metrics varies.

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Aknowledgements